

SILICON CARBIDE SEMICONDUCTOR DEVICE AND RELATED MANUFACTURING METHOD

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is related to Japanese Patent Application No. 2007-288545, filed on Nov. 6, 2007, the content of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Technical Field of the Invention

[0003] The present invention relates to silicon carbide semiconductor devices and, more particularly, to a silicon carbide semiconductor device (hereinafter referred to as "SiC") having a trench gate, and a related manufacturing method.

[0004] 2. Description of the Related Art

[0005] In recent years, a SiC has been getting a lot of attention as raw material for power devices with increased electric-field breakdown strength. Due to the SiC semiconductor device formed with increased electric-field breakdown strength, the SiC semiconductor device is able to controllably switch a flow of large electric current. Therefore, the SiC semiconductor device has been expected to have applications to a control of a motor of a hybrid vehicle.

[0006] In order for the SiC semiconductor device to pass a further increased electric current, the SiC semiconductor device needs to have an increased channel density. To this end, a silicon transistor has been put into practical use upon adopting a MOSFET of a trench gate structure. It is natural for the trench gate structure to be applied to the SiC semiconductor device. However, applying such a trench gate structure to the SiC semiconductor device A has resulted in a serious issue. That is, the SiC semiconductor device has the increased electric-field breakdown strength ten times that of the silicon semiconductor device. Thus, the SiC semiconductor device has been used under a condition applied with a voltage approximately ten times greater than that applied to the silicon semiconductor device. Thus, a gate insulation film, formed in a trench so as to penetrate the SiC, is subjected to an electric field with an intensity ten times greater than that applied to the silicon semiconductor device, causing an issue to arise with a consequence of the gate insulation film being easily broken at corner areas of the trench. Upon making a calculation on such an electric field by simulation, it has been revealed that if a drain is applied with 1200V, then an electric field of 10 MV/cm is concentrated on the gate insulation film of the trench. Accordingly, in order to withstand such a high electric field concentration in actual use, the electric field concentration needs to be 5 MV/cm or less, i.e., one-half of the electric field concentration occurring on the gate insulation film.

[0007] Devices, which can address such an issue, include a SiC semiconductor device that is disclosed in Japanese Patent Application Publication 9-199724. With such a SiC semiconductor device, a trench gate has been designed to have sidewalls and a bottom wall whose thickness is made thicker than that of the sidewall with a view to minimizing the degree of electric field concentration at the bottom wall of the trench. More particularly, a trench gate structure on "a" (1120) plane has been prepared using a (000-1) c-plane substrate with 4H SiC. When using such a c-plane substrate to prepare a gate

oxide film in the trench, having the trench sidewall placed on the "a" plane and the bottom wall placed on "c" plane, by thermal oxidation, the "c" plane has an oxidation rate five times greater than that of the "a" plane. This enables the oxidizing film of the trench bottom wall to have a film thickness five times greater than that of the sidewall. This makes it possible to minimize the degree of electric field concentration at the bottom wall of the trench.

[0008] A simulation has been conducted on such a structure in which the SiC semiconductor device has an increased gate insulation film at the bottom wall of the trench with the trench sidewall having a film thickness of, for instance, 40 nm and the trench bottom wall having a film thickness of 200 nm. Upon making a calculation based on such a simulation, it has been confirmed that when the drain is applied with 1200V, the degree of electric field concentration on the gate insulation film of the trench is reduced to a level of 6.7 MV/cm. It has been found that such a reduction in electric field concentration remains inadequate and the electric field concentration needs to be further decreased.

SUMMARY OF THE INVENTION

[0009] The present invention has been completed with a view to addressing the above issues and has an object to provide a SiC semiconductor device operative to achieve a further reduction in an electric field concentration at a gate oxide film formed in a trench and a related manufacturing method.

[0010] To achieve the above object, one aspect of the present invention provides a SiC semiconductor device composed of an inversion-type trench gate structure MOSFET. The MOSFET includes a trench formed with a gate oxide film. The gate oxide film has a bottom wall and a sidewall with the bottom wall having a greater thickness than that of the sidewall. Controlling a voltage applied to a gate electrode allows a channel region to be formed on a surface area of a base region located at the sidewall of the trench. This allows an electric current to flow between first and second electrodes via a source region and a drift layer. With such a semiconductor device, a second electrically conductive type deep layer is located in an area spaced from the trench with the base region being intervened. The deep layer is formed to have a depth approximately equal to or greater than that of the trench and has a concentration approximately equal to or greater than that of the base region.

[0011] Thus, the SiC semiconductor device of the present embodiment takes the form of a structure provided with the deep layer having the depth approximately equal to or greater than that of the trench. This allows a depletion layer, present in a PN junction between the deep layer and the drift layer, to remarkably extend to the drift layer, making it difficult for a high voltage, resulting from an affect caused by a drain voltage, to be applied to the gate oxide film. This enables an electric field concentration in the gate oxide film, i.e., an electric field concentration in the gate oxide film especially at the bottom wall of the trench to be alleviated.

[0012] Although the present invention has been described above with reference to the SiC semiconductor device of the inversion-type trench gate structure, the present invention may be implemented in a modified structure. That is, a SiC semiconductor device composed of an accumulation-type trench gate structure MOSFET can adopt the same structure as that mentioned above with the resultant same advantageous effects as those mentioned above. With such an accu-